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Relationship between level of economic development and motorcycle and car ownerships and their impacts on fuel consumption and greenhouse gas emission in Thailand

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ABSTRACT

An increase in road vehicles secondary to economic development has strongly pushed up energy demand and adversely impact the environment by the emission of greenhouse gases and pollutants. This paper aims to analyse the relationship between motorcycle and car ownerships and level of economic development in Thailand. In addition, an overall private vehicle ownership which is a sum of both types of private vehicle ownership is also studied. An understanding of these relationships due to the economic development is a key knowledge for the sustainable transport policy in the future.

The results of this study revealed that at the early stage of economic development of developing countries like Thailand, the number of motorcycles predominates over private cars. Economic development strongly affects the ownership of private vehicles in two ways: (1) overall private vehicle ownerships increase as the income levels grow and (2) after personal income grows up to a certain level, people will shift from motorcycle to car ownerships for their prestige, convenience, comfort and safety. Because of continuing economic development and population growth, the expected increase in overall private vehicle ownership is projected to push up the total private vehicle stock of Thailand in the year 2050 to about twice of the present level. This will drive fuel demands in 2050 to about 2.4 times, and the greenhouse gases (GHG) emission to about 2.5 times of the current levels.

Hence, policy makers in developing countries should not overlook the impacts on the consequences of increasing overall private vehicle stock in the near future. The best and most appropriate policies should be given to the development of public transport as the first priority rather than the traditional one, which gives highest priority to traffic mobility of private vehicles by road transport neglecting the effectiveness of passengers' mobility of the public transport. In addition, policies to promote high efficiency vehicle technologies, particularly for motorcycles, should also be taken into consideration, particularly for a low income country due to a high share of the motorcycles in the overall private vehicle stock.

Contents

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1. Introduction

Historically, transport demand is closely related to advancement in economic development. Rapid growth rate of private vehicle ownership during the past three decades, especially in developing countries, has continuously raised energy demands and emissions in the road transport sector. Due to difference in level of economic development, private vehicle ownership characteristics in developing countries are significantly different from that of developed countries.

Fig. 1 depicts a relationship between motorcycle and car ownership for developing and developed countries in 2005 [1]. The diagonal represents a tracing line of equal numbers of the ownership between motorcycles and cars. Countries whose plotted points are below the diagonal line have higher car ownership than motorcycle ownership; it is obvious that all of them are well developed countries. On the other hand, all plotted points above the diagonal line belong to developing countries where motorcycle ownerships are higher than car ownerships. All developed countries presented in Fig. 1 have a per capita gross domestic product (GDP) over 15,000 USD, while all developing countries presented in the same figure have per capita GDP lower than 5000 USD. Hence, we can draw a conclusion from this figure that motorcycles ownerships contribute a higher share of private vehicles ownerships in countries with low per capita income, and vice versa.

Over the past two decades, Thailand is one of the faster emerging economies of the developing countries. During that time, motorcycle ownerships have always greatly outnumbered car ownerships in the private transport mode, but currently car ownerships are gradually gaining ground as the country's economy steadily advances.

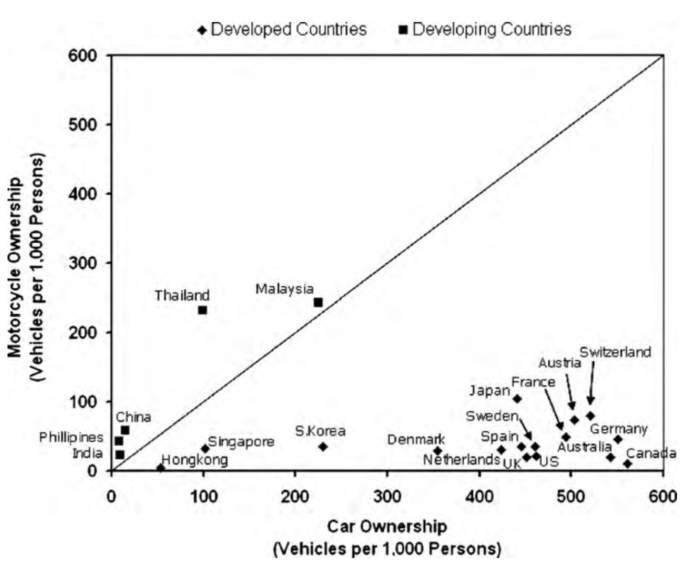


Fig. 1. Motorcycle and car ownership of selected countries.

Several research studies have been conducted on the private vehicle ownership of developing countries including Thailand. Most of these researches focused only on the ownership of cars rather than that of motorcycles. Car and motorcycle ownership were separately formulated in the afore-mentioned researches without exploring in depth whether there is a close relationship between car and motorcycle ownership with the stage of economic development.

Since it is likely that number of private vehicles, both motorcycles and cars, in Thailand will dramatically increase in the near future, it would play an increasingly important role in raising greenhouse gas (GHG) emissions and the demand on oils by the road transport sector. In order to obviate these problems, it is necessary to investigate the characteristics of the private vehicle ownership in Thailand in relation to the economic development.

The purposes of this study are to investigate a relationship between motorcycle and car ownerships as a function of economic development in Thailand and how this relationship evolves as a consequence of the economic development. Moreover, the peak number of motorcycle ownership and the saturation level of overall private vehicle ownerships will also be explored.

2. A brief review of vehicle ownership models

Several models of private vehicle ownership have been developed because of its importance in transport planning and other activities as required by the government, car manufacturers, and environmental protection groups. Various techniques have been developed [2]. Since the private vehicle ownership is generally related to socio-economic development, econometric techniques are commonly deployed. A relationship between the vehicle ownership and socio-economic driving factors has been developed to relate with behavior of consumers in owning private vehicles. Generally, techniques for private vehicle ownership modeling are dictated by the complexity of hierarchical data structures. Private vehicle ownership models can be distinguished into two approaches: aggregated and disaggregated models.

The aggregated models are developed using aggregated input data at a national, regional or local levels [3–6]. A relationship between a dependent variable of the vehicle ownership and influencing socio-economic parameters is formulated. The advantage of this type of modeling is that the models can be easily formulated without any necessity of an extensive survey input data.

The disaggregated models have been developed in many developed countries [7,8]. Numbers of private vehicle ownership are generally formulated from various factors at the elementary level of end-users. They are currently commonly used in most well developed countries because they can clearly present the effects of those influencing socio-economic parameters on the ownership of private vehicles as affected by the individuals. However, to develop the disaggregated models, extensive socio-economic data surveys are needed at the elementary level of individuals.

Because of the dearth of well recorded observed data at the elementary level of individuals (or end-users) in most developing countries, the disaggregated modeling approaches are rarely adopted and the aggregated modeling techniques are generally preferable in these countries.

2.1. Cars ownerships

In the early stage of the development of the aggregated models, the linear and logarithmic functions were used for long-term forecasting [3]. However, later researchers found that these models placed no limit to the numbers of the vehicle ownership and the numbers of vehicle ownership in horizon years tend to explode. To avoid such exploding numbers of the vehicle ownership in the long-term forecasting, an S-curve function with the saturation level of the vehicle ownership has been introduced. An example of this type of function is the logistic function [4]. With this function, numbers of the vehicle ownership increase slowly during the early period of economic development when the earning income levels are low; as the level of earning income rises further, the numbers of the vehicle ownership enter a rapid growth phase; and finally, the growth rate gradually slow down and the numbers of vehicle ownership asymptotically approach a saturation level. A general form of the logistic function is given by Eq. (1):

$$V = \frac{S}{1 + e^{-a} X_1^{-b_1} X_2^{-b_2} \ldots X_n^{-b_n}} \quad (1)$$

where V is the vehicle ownership (number of vehicles per capita), S is the saturation level of the vehicle ownership, $X_1, X_2, \ldots, X_n$ are a set of influencing parameters on the ownership and $a, b_1, b_2, \ldots, b_n$ are coefficients of the model.

The ownership of private vehicles is strongly influenced by those socio-economic parameters and other transport factors such as per capita GDP, motoring cost, urbanization, average fuel price and population density.

Unfortunately, in most developing countries, not all parameter data mentioned above are available. In practice, per capita GDP is the sole parameter used as the key influencing variable for the growth of the vehicle ownership in most researches in developing countries.

2.2. Motorcycle ownerships

Based on our reviews, we found that only a few studies of motorcycle ownerships have been carried out so far. Most of studies were conducted in Eastern Asian countries, such as Japan, Taiwan, Malaysia, Vietnam, Thailand [6,9–12] and a few studies were conducted in the United Kingdom [13].

Motorcycle ownership characteristics are somewhat different from that of car ownerships. Experiences in developed countries show that motorcycle ownerships gradually increase with the income growth during early stage of economic development until it reaches a peak when the incomes of people reach a certain level and then starts to decline as incomes rise further. Hence, an S-shaped curve does not provide a good fit with an actual observation of motorcycle ownership [11] because this function asymptotically approaches a saturation value without the peak value. Thus, in order to overcome such a discrepancy, Sillaparcharn [6] has proposed the use of a quadratic log-linear functional form for curve fitting for the motorcycle ownerships, as presented in Eq. (2). The model assumes that the number of private motorcycle ownership peaks when the average consumers' income approaches a certain level, after that it will gradually decline and replace by private car ownership. He suggested that the quadratic term of the number of car per one thousand inhabitants $(\log C1000)^2$, should be added to the motorcycle ownership model in Eq. (2) to predict a decline in the motorcycle ownership. However, this equation does not explicitly couple together a relationship between the number of motorcycle ownership and those of car ownership and does not give varying proportion of vehicle types due to the influence of economic development.

Furthermore, he assumed that the two-wheeled private vehicle ownership was driven by similar socio-economic parameters as those proposed for the car ownership modeling as follows:

$$\log MC1000_i = a + b_1 \log GPP\,pH_i + b_2(\log GPP\,pH_i)^2 + b_3 Dist_i + b_4 \log C1000_i + b_5(\log C1000)^2 \quad (2)$$

where $MC1000_i$ is the number of motorcycle per 1000 inhabitants for province i in Thailand, $GPPpH_i$ is gross provincial product per household for province i, $Dist$ is linear distance of provincial i from Bangkok and $C1000$ is the number of car per 1000 inhabitants for province i, and a, b_1, b_2, b_3, b_4 and b_5 are coefficient of influencing variables.

However, in all studies mentioned earlier except for that of Sillaparcharn, we found that none had developed the associated proportion between the ownership of cars and that of motorcycles. These two types of vehicles were always treated separately and independently without considering their interaction in the private vehicle ownership and did not investigate how the associated proportion was influenced by the growth of economic development in a country.

At the outset, we planned to use the model developed by Sillaparcharn for this study. Unfortunately, after verifying Eq. (2) with our most current, updated data, we found that there is a serious discrepancy of the model with actual motorcycle ownership. The ownership of the motorcycle was greatly underestimated after it had peaked. Hence, we decided to formulate a new model by using the logistic function of Eq. (1).

3. Methodology

The private vehicle ownership models in this study have been developed by employing associated data from various official data sources of Thailand. The estimated private vehicle ownership from the models had been verified with the actual observed ones, and subsequently they were used to forecast the number of private vehicle ownerships and stocks. The extrapolated private vehicle stocks were then investigated for their fuel consumption and GHG emissions in the road transport sector in the future up to year 2050. The details of the methodology in this study are given as follows.

3.1. Data collection

The collected data used in this study were obtained from various official data sources in Thailand during 1991 to 2007, as shown in Table 1 [14–16].

3.2. The development of model for private vehicle ownership in Thailand

In this study, numbers of car and of motorcycle ownership were pooled together and counted as the number of an overall private vehicle ownership. The character of the overall private vehicle ownership is similar to that of the car ownership which generally grows slowly during the early period of the economic development. However, it rapidly increases as soon as the earning income of people rises until it asymptotically approaches a saturation level when the earning incomes of the people increase further. Hence, the ownership of the overall private vehicle can be characterized

Table 1
Detail of collected data.

Data	Description	Time period	Sources
Number of vehicles	Annual registered numbers for each type of vehicles	1991–2007	Department of Land Transport (DLT)
Gross domestic product	Gross domestic product of Thailand (based on 2007 price)	1991–2007	The Office of National Economic and Social Development Board (NESDB)
Population	Annual population of Thailand	1991–2007	The Office of National Economic and Social Development Board (NESDB)

by the S-curve function. Here the logistic function was adopted to predict the overall private vehicle ownership.

We expect that in Thailand, as in other fast emerging economies of developing countries, there are two basic socio-economic parameters, i.e. GPD and population, which strongly influence the ownership of private vehicles. However, these two parameters are inter-correlated. In order to avoid a multicollinearity effect, we decided to merge them into a single parameter as a term of per capita GDP and it was used as the independent, driving variable for an overall vehicle ownership, as given in Eq. (3):

$$V_{\text{overall},t} = \frac{S}{1 + e^{a} \cdot G_t^{-b}} + c \cdot D_t + \varepsilon_t \tag{3}$$

where $V_{\text{overall},t}$ is an overall vehicle ownership (vehicles per 1000 persons) at year t, S is a saturation level of the overall vehicle ownership (vehicles per 1000 persons), G_t is a real per capita GDP (baht per person, at the year 2007 price) at year t, D_t is a dummy variable in year t, a, b and c are coefficients of the model and ε_t is an error term.

Although there is strong evidence for the interaction between the ownership of cars and motorcycles, most of existing mathematical models treated the ownership of each vehicle type separately. Hence, it is likely that they could not accurately represent and predict the actual private vehicle ownership. To rectify this deficiency in existing models, in this study, the association of the relationship between both types of private vehicles has been taken into account and developed, to be correlated with economic development.

Based on the argument mentioned above, we develop a model to represent proportion of private car to that of overall private vehicle ownerships in relationship with economic development. As people earn higher incomes, they prefer to own cars rather than motorcycles because of the cars' comfort, convenience and safety. As a result, the proportion of cars to the overall private vehicle ownership grows when incomes rise. Since the number of car ownership is expected to keep growing until it approaches the number of the overall private vehicle ownership (in other word, the ownership of motorcycles is fully replaced by that of cars), the S-curve function of Eq. (3) can again be used for predicting the proportion of the private cars to the overall private vehicle ownership as a function of per capita GDP.

Since the highest possible value of the proportion of the ownership of the private cars to that of the overall private vehicles is "1". Hence, the saturation value of "S" in the logistic function of Eq. (3) is "1". Consequently, the model of Eq. (3) can be modified as shown in Eq. (4):

$$p_t = \frac{1}{1 + e^{\alpha} \cdot G_t^{-\beta}} + \gamma \cdot D_t + \varepsilon_t \tag{4}$$

where p_t is a proportion of the ownership of cars to that of the overall vehicles at time t, and α, β and γ are coefficients of the model.

The number of car ownership can be calculated from the product of the proportion of the cars to the overall private vehicle ownership and the number of the overall private vehicle ownership as presented in Eq. (5):

$$V_{\text{car},t} = p_t \times V_{\text{overall},t} \tag{5}$$

where $V_{\text{car},t}$ is the number of car ownership (vehicles per 1000 persons) at time t.

Finally, the number of motorcycle ownership can be calculated from the product of $(1 - p_t)$ and the number of the overall private vehicle ownership, $V_{\text{overall},t}$, as presented in Eq. (6):

$$V_{\text{motorcycle},t} = (1 - p_t) \times V_{\text{overall},t} \tag{6}$$

where $V_{\text{motorcycle},t}$ is the number of motorcycle ownership (vehicles per 1000 persons) at time t.

Annual numbers of the overall private vehicle ownership and annual proportions of the cars to the overall private vehicle ownership were regressed with annual per capita GDP during 1991 to 2007. To estimate the values of coefficients in Eqs. (3) and (4), the ordinary least square (OLS) method was employed to calculate the mentioned parameters at a statistical 95% confidence interval.

The results of the developed models to predict the numbers of the overall private vehicle ownership and the proportions of the cars to the overall private vehicle ownership are given in Eqs. (7) and (8), respectively:

$$V_{\text{overall},t} = \frac{556}{1 + e^{41.105} \cdot G_t^{-3.555}} + 49.982 D_t \tag{7}$$

with coefficient of determination, $R^2 = 0.92$:

$$p_t = \frac{1}{1 + e^{6.440} \cdot G_t^{-0.487}} - 0.5 D_t \tag{8}$$

with coefficient of determination, $R^2 = 0.80$.

By substituting $V_{\text{overall},t}$ and p_t from Eqs. (7) and (8) into Eqs. (5) and (6), one can obtain the number of car ownership and that of motorcycle ownership, respectively.

3.3. Verification of the model

Results of the estimated numbers of the overall private vehicles, the car and the motorcycle ownership from Eqs. (3), (5) to (6) were compared with the actual observed numbers. The goodness of fit between the predicted numbers of private vehicle ownership and the actual observed ones can be indicated by determining the coefficient of determination (R^2), the percentages of the mean bias error (MBE) and the root mean square error (RMSE) of the estimation, as given in Eqs. (9), (10) and (11), respectively, shown below:

$$R^2 = \frac{\left[\sum_{i=1}^{n} (y_i - \bar{y})(\hat{y}_i - \bar{y})\right]^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2 \sum_{i=1}^{n} (\hat{y}_i - \bar{y})^2} \tag{9}$$

where R^2 is a coefficient of determination, $\hat{y}$ is an estimated value, y is an observed value i, $\bar{y}$ is a mean of the observed values and n is

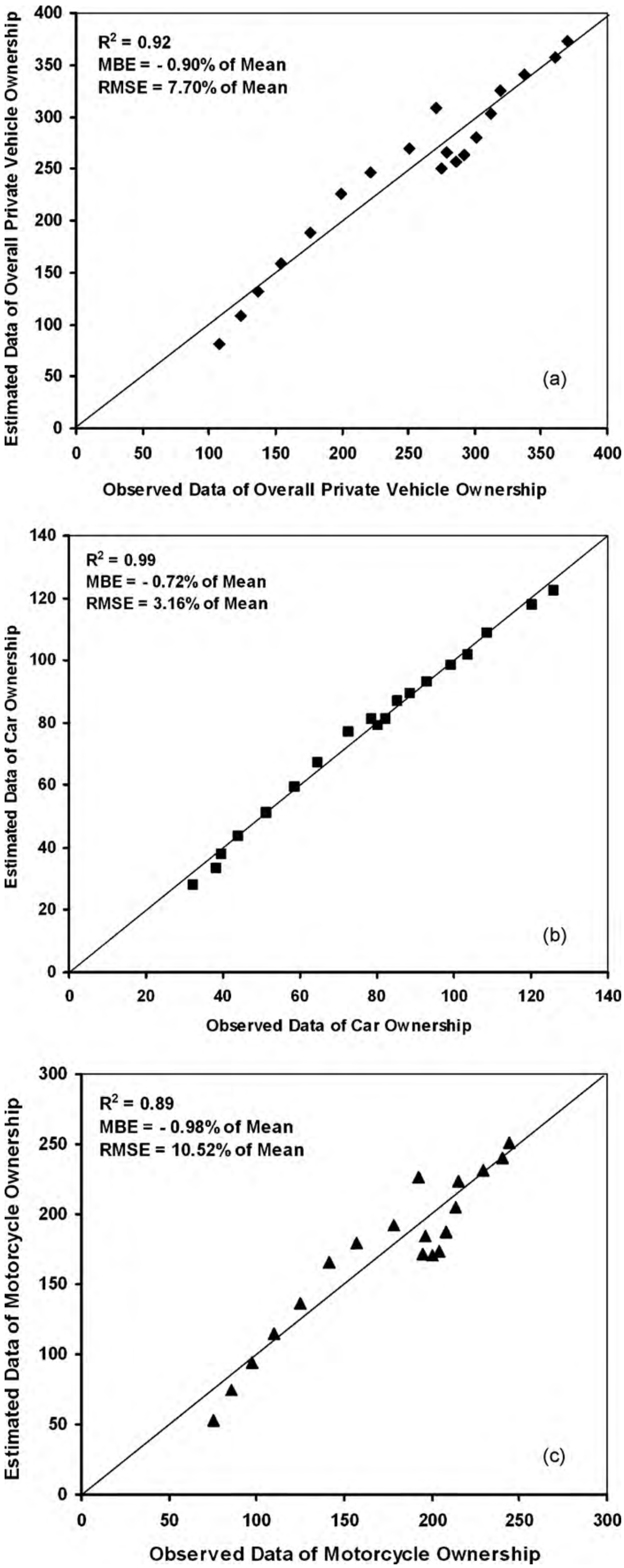


Fig. 2. Verification results of (a) overall private vehicle ownership, (b) car ownership and (c) motorcycle ownership.

number of the data set.

$$\text{MBE} = \frac{\sum_{i=1}^{n} (\hat{y}_i - y_i)/n}{\bar{y}} \times 100 \qquad (10)$$

where MBE is the percentage of a mean bias error of an estimation.

$$\text{RMSE} = \frac{\sqrt{\sum_{i=1}^{n} (\hat{y}_i - y_i)^2/n}}{\bar{y}} \times 100 \qquad (11)$$

where RMSE is the percentage of a root mean squared error of an estimation.

As shown in Fig. 2, there are good fits between the estimated and actual vehicle ownerships with high values of R^2 0.99, 0.99 and 0.98, for the overall, car, and motorcycle ownership respectively. Errors of estimations are quite low with satisfactory results; the relative percentage errors for MBE and RMSE are lower than 1.0% and 8.0% of the mean values respectively. But the RMSE of motorcycle ownership is slightly higher at 11.0% of the mean value.

3.4. Forecasting of private vehicles ownership

After having verified the models, they were then used to forecast the private vehicle ownership from 2008 to 2050. In the prediction, we assume that the average annual growth rate of GDP and population of Thailand are as follows:

- Average GDP growth rate is 4.5% per annum.
- Average population growth rate is 0.6% per year.

Both assumed figures were determined from the average values of the historical data of the years 1991–2007. These data were obtained from the Office of National Economic and Social Development Board of Thailand (NESDB). Results of forecasts on private vehicle ownership and private vehicle stocks will be presented and discussed in Section 4.

3.5. Forecasting stocks for cars and motorcycles

Annual number of stocks for cars and for motorcycles can be calculated by the following equations:

$$S_{\text{car},t} = (p_t \times V_{\text{overall},t}) \times P_t \qquad (12)$$

where $S_{\text{car},t}$ is the number of car stock at year t and P_t is the number of population in year t, and

$$S_{\text{motorcycle},t} = [(1 - p_t) \times V_{\text{overall},t}] \times P_t \qquad (13)$$

where $S_{\text{motorcycle},t}$ is the number of motorcycle stock at year t.

The number of the overall private vehicle ownership, $V_{\text{overall},t}$, and the proportion of cars ownership, p, can be obtained from Eqs. (7) and (8), respectively.

3.6. Forecasting fuel demands and GHG emissions

Fuel demands and GHG emissions were projected for next 40 years under the Business As Usual (BAU) scenario, i.e., it was assumed that there are no changes in vehicle technologies and other related influencing factors are assumed to be similar to the present condition.

The total private vehicle stocks for motorcycles and cars in each year obtained from Eqs. (12) to (13) were multiplied by their corresponding annual average fuel consumptions to yield total annual fuel demand and GHG emissions for each vehicle type from years 2008 up to 2050.

Table 2
Average annual fuel consumption and corresponding annual average ghg emission of private vehicles.

Vehicle type	Averaged annual fuel consumption (toe per vehicle-year)	Averaged annual GHG emission (kg of CO_2 equivalent per vehicle-year)
Motorcycle	370	604
Car	1296	2396

Remark: 1 t of crude oil equivalent (toe) = 42,244 MJ.

In this study, annual average fuel consumption per vehicle for cars and that for motorcycles were based on the field survey of the Energy Policy and Planning Office (EPPO) in 2007 [17]. GHG emissions from tailpipe exhausts were determined only for CO_2, CH_4 and N_2O and were converted to a total CO_2 equivalent emission. The GHG emission factors for each type of gas emissions were referenced on the tier one's default values of Intergovernmental Panel for Climate Change (IPCC) [18]. Table 2 presents the annual average fuel consumption per vehicle for each type of vehicles, and the corresponding annual average GHG emissions.

4. Results and discussion

4.1. Private vehicles ownership in Thailand

The projected private vehicle ownership for overall, cars, and motorcycles from years 2008 to 2050 are illustrated in Fig. 3. Their proportions as a percent share of each vehicle type to the overall private vehicle ownership are given in Fig. 4.

The results show that, in Thailand, economic development strongly affects the private vehicle ownership in two ways. Firstly, overall private vehicle ownerships are tied to the level of economic development. As earning income rises, it stimulates people to own more private vehicles either as a motorized two-wheeled (motorcycle) or a four-wheeled (car) technology. Secondly, the proportions of car ownership gradually increase as earning incomes rise and the ownership of cars will eventually dominate the ownership of the overall private vehicles when the average earning incomes of Thai people reach a certain value.

4.1.1. Trends of overall private vehicle ownership in Thailand

The results demonstrated that trends of growth in overall private vehicle ownership in Thailand is similar to most developed countries; growth of overall private vehicle ownership is driven by per capita GDP growth and will asymptotically approach a saturation ownership level in the long-term. In this study, as presented in Fig. 3, we estimated that the saturation level of the overall private vehicle ownership of Thailand will be around 560 vehicles per thousand persons when the per capita GDP of Thailand is about 12,900 USD. The estimated saturation level of the overall private vehicle ownership in this study was found to be of the same range of magnitude to the current ownership in many well developed countries, namely Australia, Canada, France and Japan [1].

4.1.2. Transition of a change of the technological structure from motorcycle to car ownership

Fig. 4 shows percent shares of cars and motorcycles to the overall private vehicle ownership. At the early stages of economic development, average earning income of population is generally low; people tend to purchase more motorcycles for their private transport needs since only a small fraction of people who can afford to own expensive cars. As a result, motorcycle ownership generally contributes a higher share of the overall private vehicle ownership. For instance, when per capita GDP in Thailand was about 2164 USD in 1991, the percent share of motorcycle ownership was 72% of the overall private vehicle ownership, while the percent share of car ownership was only 28%.

This gap gradually narrows when the average earning incomes of population increase; the numbers of people who can afford cars become greater because of rises of their purchasing power. When the income levels rise, the percent share of car ownership increases in parallel. For example, when Thailand's per capita GDP was about 3674 USD in 2007, the percent share of motorcycle ownership dropped to 66% of the overall private vehicle ownership, and the percent share of car ownership increased to 34%. As a consequence, the percent share of motorcycle ownership eventually peaks at a certain level of average annual income and then declines. In this study, the motorcycle ownership in Thailand is expected to peak at 316 vehicles per thousand persons when per capita GDP is 6753

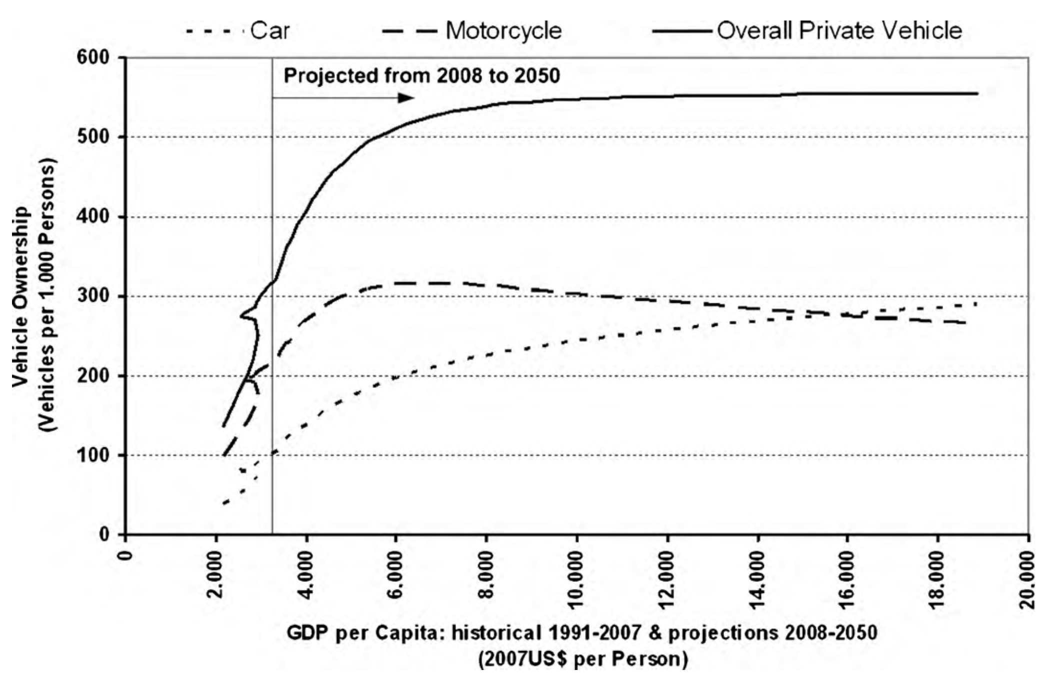


Fig. 3. Historical and projected private vehicle ownership to 2050.

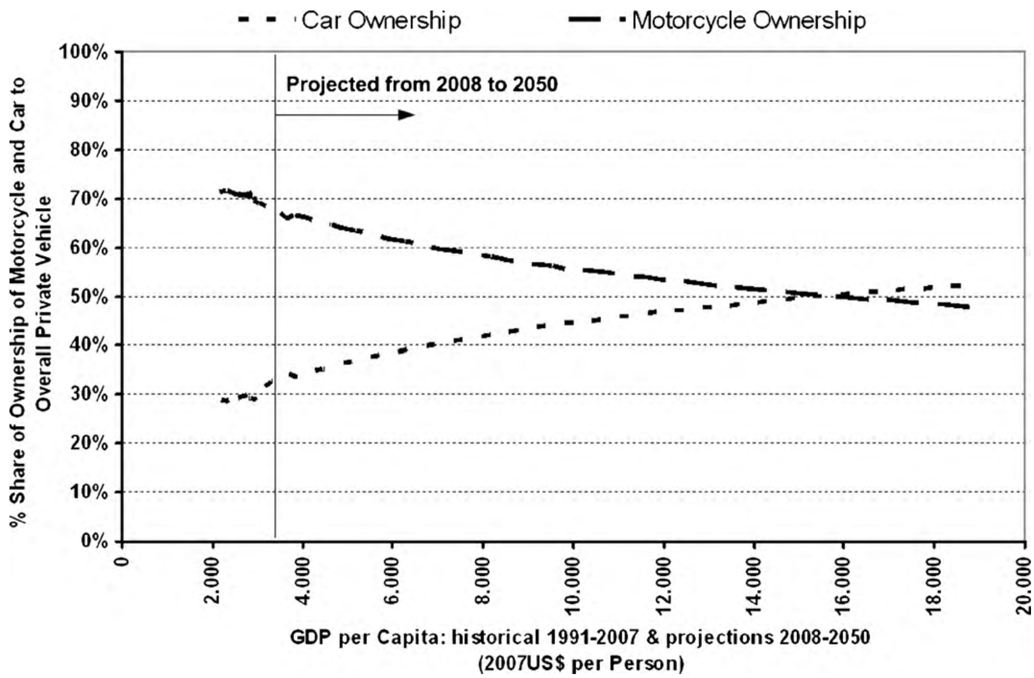


Fig. 4. Historical and projected % shares of motorcycles and cars to 2050.

USD as shown in Fig. 3. The estimated peak motorcycle ownership in our calculation is similar to that of Sillaparcharn [6] and Hsu [11] for the motorcycle ownership in Thailand and Malaysia, a neighboring country of Thailand, which were found to be 350 and 339 vehicles per thousand persons, respectively.

It should be remarked here that the peak motorcycle ownerships in Thailand and Malaysia are much higher than those which have already occurred in developed countries in the last two decades. These differences can be explained by the fact that current purchasing powers of both countries are still considerably lower than past purchasing powers of well developed countries. From the point of view of consumers in Thailand and Malaysia, the price of motorcycles is much more affordable than cars considering their income levels. Therefore, the growth rate of motorcycle ownership is currently still much higher than that of car ownership. This leads to higher peak numbers of motorcycle ownership as compared to that of well developed countries in the past.

The car ownership in Thailand is expected to be equal to motorcycle ownerships when per capita GDP of Thailand is about 15,600 USD. This means that, above this income level, the ownership of cars will be the predominant portion of overall private vehicles ownership similar to those in well developed countries. We expect this pattern of change in the ownership structure of overall private vehicles from motorcycle to car predominance to be likely the case in all economically fast-growing developing countries such as China, India and Vietnam, where the earning incomes of people have been continually growing.

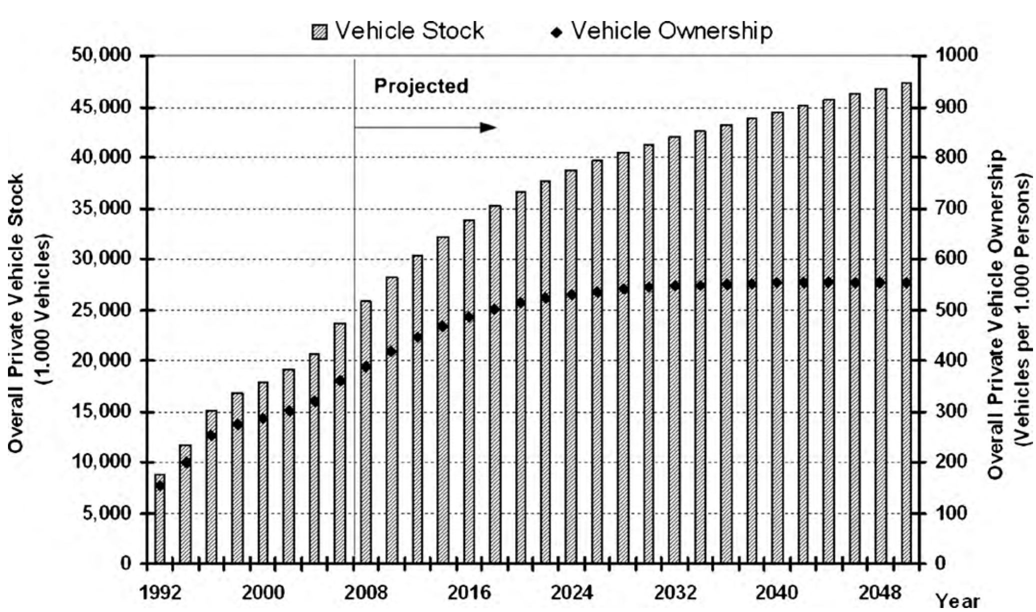


Fig. 5. Trends of overall private vehicle ownership and stock to 2050.

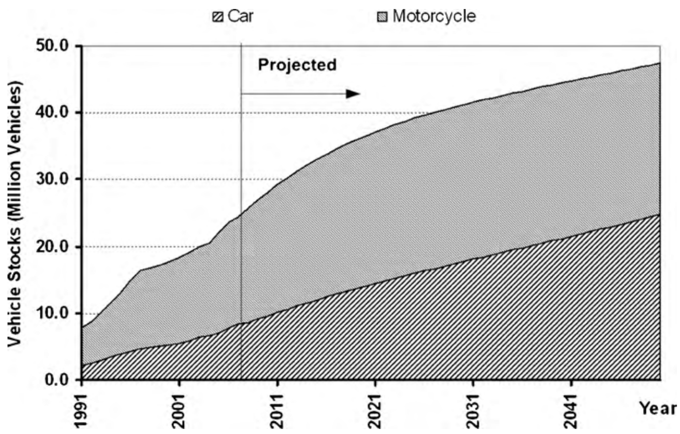


Fig. 6. Projection of private vehicle stocks to 2050.

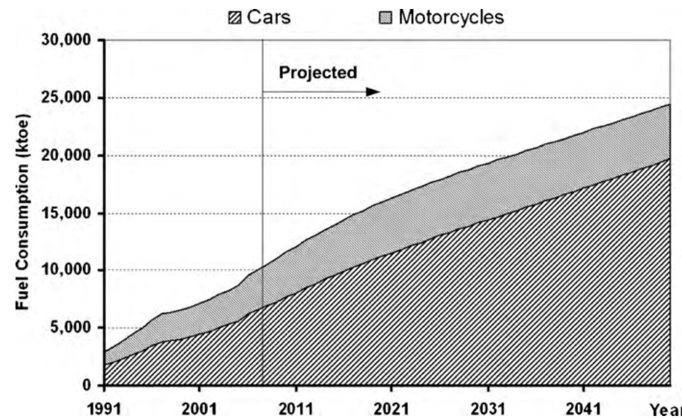


Fig. 8. Projection of fuel consumption of private vehicles by vehicle type to 2050.

4.2. Implication of a growth in private vehicle ownership and stocks on fuel demands and GHG emissions

4.2.1. Trends of private vehicle stocks

As mentioned in Section 4.1, an overall private vehicle ownership in Thailand would be saturated at similar level as that of current ownerships in many well developed countries. It should be remarked here that the ownership of private vehicles is a normalized value of possessed vehicles per thousand persons. As a result, the annual total private vehicle stock will continue to grow because of population growth, even though the normalized overall private vehicle ownership is saturated. Hence, the total fuel demands and GHG emissions in the road transport sector will also increase in line with the growth of overall private vehicle stocks, as presented in Fig. 5.

Figs. 6 and 7 present annual private vehicle stocks and the share of each type of the private vehicle stocks in Thailand. Since the overall private vehicle ownership is driven by the rise of earning incomes in conjunction with population growth, this will result in a large number of total private vehicle stocks in the future. It is expected that this number will increase from 25.86 million in 2008 to 47.4 million vehicles in 2050, almost twice of the current overall private vehicles.

The current year 2008 stock consists of 16.1 million motorcycles and 8.3 million cars. However, year 2050 stock will increase up to 22.6 million for the motorcycles and up to 24.8 million for cars respectively, representing an increase of 1.4 times for motorcycle and almost 3 times for car within the next 40-year span. Motorcycles currently share about 66% of the overall private vehicle stock in 2008 and they will gradually decrease to a share of about 48% in 2050.

4.2.2. Fuel demands and GHG emissions of private vehicle stocks

Figs. 8 and 9 depict the long-term trends of fuel demands and GHG emissions from motorcycles and cars in Thailand. It shows that, in 2008, the total fuel consumption of the overall private vehicles was 10,481 kilotons of crude oil equivalent (ktoe) while the total fuel consumption in the passenger transport sector in Thailand was estimated to be 14,957 ktoe [19]. Hence, the overall private vehicles' fuel consumption shared almost 70% of the total fuel consumption of the passenger transport sector in 2008 whereas the public road transport shared only 30% even though it is much more energy efficient than the private transport for mobilizing passengers. This reflects poor past transport planning of Thailand for sustainability.

The fuel consumption of the overall private vehicles is expected to increase to 24,449 ktoe in 2050 which is about 2.4 times of the current fuel consumption. The total GHG emissions will increase from 31.1 million tons of CO_2 equivalent (Mt of CO_2-eq) in 2008 to 73.0 Mt of CO_2-eq in 2050, or about 2.5 times of the current value.

The fuel consumption of private cars is expected to grow from 6880 ktoe in 2008 to 19,712 ktoe in 2050 which is almost 3 times of the current value. Meanwhile, the consumption of motorcycles will rise from 3601 ktoe in 2008 to 4737 ktoe in 2050, a 1.3 times increase from the present consumption.

The GHG emissions of private cars and motorcycles are estimated to be about 20.7 and 10.4 Mt of CO_2-eq in 2008

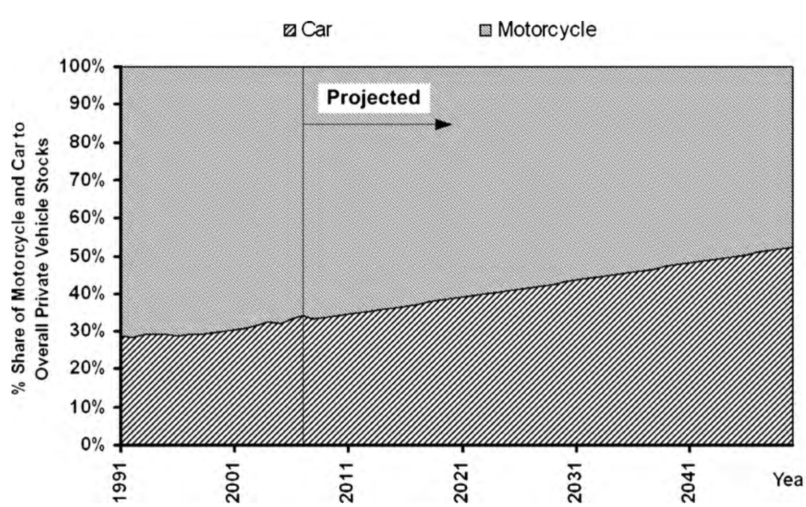


Fig. 7. Projection of % shares of motorcycle and car to 2050.

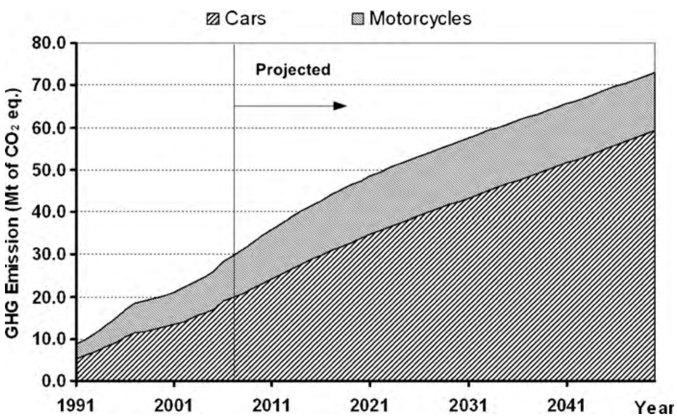


Fig. 9. Projection of GHG emissions of private vehicles by vehicle type to 2050.

respectively. In 2050, these emissions are projected to emit about 59.3 Mt of CO_2-eq from cars and 13.7 Mt of CO_2-eq from motorcycles. The amount of GHG emissions from private cars and that of motorcycles will increase to be about 2.9 and 1.3 times of the current year 2008 respectively.

4.2.3. Percentages of fuel demands and GHG emissions shared by private car and motorcycle stocks

Figs. 10 and 11 show the percent of fuel demands and GHG emissions shared by car and motorcycle stocks. Even though the per vehicle fuel consumption of motorcycles is not as large as that of private cars, the very large number of motorcycle stocks contributed significant proportions of total fuel consumption and GHG emissions of the total private transport sector at the onset of economic development. In 1991, it was estimated that motorcycles consumed about 40% of the total fuel consumption of the private transport. However, because of a decline in motorcycle ownership and an increase in car ownership due to economic development, the share of fuel demands and that of GHG emissions from the motorcycle stocks will be reduced to only about 20% of the total fuel consumption and about the same figure of 20% for GHG emissions in 2050. Although the percent shares of fuel demands and GHG emissions of motorcycles will be less in the future, it should be kept in mind that the absolute total amounts of fuel demands and GHG emissions from the motorcycles stock will continue to grow due to the rise of total numbers of the motorcycle stocks as mentioned above.

Although the numbers of car stocks are lower than those of the motorcycle stocks in the early period of economic development, the fuel economy of cars is generally poorer than that of

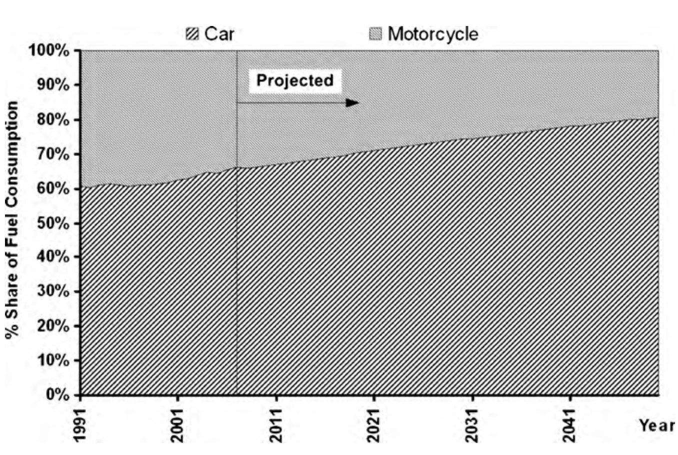


Fig. 10. Projection of % share of fuel consumption by vehicle type to 2050.

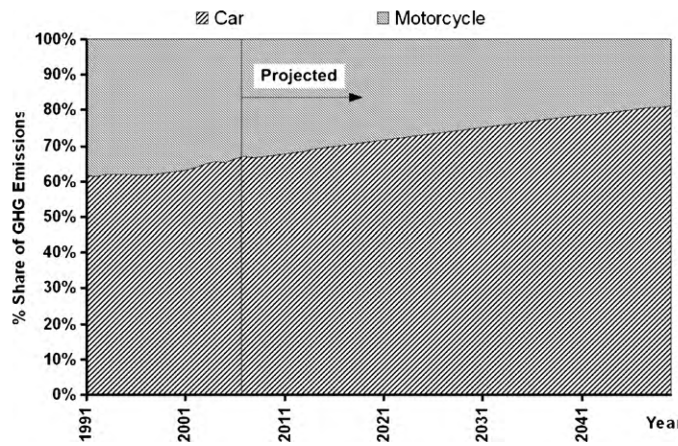


Fig. 11. Projection of % share of GHG emissions by vehicle type to 2050.

motorcycles. As a result, the total fuel consumption and GHG emissions shared by cars have been larger than those of motorcycles even before 1991. They have consumed more than 60% of total fuel consumption of private passenger vehicles since 1991. It is expected that the situation would be even worse because of the projected large increase in future car ownerships especially beyond the point of peak motorcycle ownership. Because of the increase in the numbers of car stocks, the fuel consumption of cars is estimated to acquire more than 80% share of the total fuel consumption of the private transport sector in 2050.

4.3. Policy recommendation

In the emerging economy of developing countries like Thailand, the private transport mode currently shares more than two-third of the total fuel consumption for the passenger transport sector.If this continues to grow as a result of economic development, accumulation of overall private vehicle stocks will seriously push up total fuel demands and GHG emissions of the road transport sector in the not too distant future. Not only would they consume fuels voraciously and emit large amounts of pollutants, but large extensive networks of infrastructures for road transport to support passenger traffic mobility would also be needed.

From the point of view of sustainable transport planning, the current growth trend in the overall private vehicle stock is quite unfavorable for sustainable development. Thus appropriate policies and measures should be urgently implemented to mitigate future growth of the private vehicle ownerships for both types of vehicles.

It is clear from this study that, economic development is the key driving factor for the need of the passenger transport. Even at the early stages of economic development when the majority of people's earning incomes are still low, there usually is large demands in private vehicle ownership using two-wheeled motorized private vehicles. Although the fuel consumption of a single unit of motorcycles is much lower than that of cars, however, large number of motorcycle stocks can contribute a significant share to the total fuel consumption and GHG emissions of the passenger transport sector. Without proper and thoughtful planning and policy, in developing countries like Thailand, it is quite common that this issue and its consequences are often overlooked or neglected. It is high time that this issue receives serious attention from policy makers.

As mentioned earlier in Section 4.1.2, as the earning incomes of people in a developing country like Thailand improve, the situation will become even worse as most consumers will likely prefer to purchase more cars than motorcycles. Thus, the structure of the overall private vehicle ownership of a country starts to shift from

motorcycle to car predominant. Since the fuel economy of a unit of cars is generally much worse than that of a motorcycle, it will generate even greater demands for fuel consumption and release more GHG and other pollutants. From the point of view of sustainable transport policy, suppression or delay in a mode shift from motorcycles to cars by persuading people to use more public transport or non-motorized transport mode rather than upgrading their motorcycles to cars for short distance traveling is crucial for the development of sustainable transportation at the national level.

Traditionally, most of the fast-growing economies of developing countries tend to pay more attention to the development of large extensive infrastructure of road and highway networks to support dramatic increase in local traffic demands from road transport vehicles. The traditional road transport policy giving high priority to private transport is unlikely to solve the transportation problems in the long-term. On the contrary, the government should give high priority to develop infrastructures for the public transport and non-motorized transport rather than focusing on supporting private vehicle mobility which, in turn, will eventually stimulate more people to own more private vehicles for passenger transport.

In addition, since motorcycles are frequently used for short and medium distance traveling particularly in urban areas, in order to save energy and to abate pollutant emissions from motorcycles, the government and policy makers in developing countries should not be lured by the low consumption per unit of motorcycle but should instead focus now on how to improve on their fuel economy and efficiency as much as that of cars, and to develop policies to promote new environmental friendly vehicle technologies such as electric motorcycles to replace the traditional internal combustion engine technology.

5. Conclusion

This study reveals that, at the early stage of economic development of developing countries like Thailand, motorcycles are dominant for the overall ownership of private vehicles and economic development is the key driver that strongly affects the ownership of private vehicles in two ways. Firstly, overall private vehicle ownership increases as income levels grow. Secondly, although overall private vehicle ownership is dominated by motorcycle at the early stage of economic development, however, as soon as the income level increases to a certain level, consumers will shift from motorcycles to cars due to its convenience, comfort and safety.

Since motorcycles play an important role in the private transport mode in developing countries, the domination of large number of motorcycles over the overall private vehicle ownership and their importance should not be overlooked by policy makers because not only do they consume a large proportion of total fuel consumption in the road transport sector, but they also emit a large amount of greenhouse gases and other pollutants. Moreover, the situation will become even worse after consumers shift their ownership from motorcycles to cars because the fuel economy per unit vehicle of cars is much worse than that of a motorcycle. Consequently, to cope with these looming impacts, national road transport policies must give high priority to public and non-motorized transport mode as well as promoting highly energy efficient vehicle technologies to support the development of sustainable transportation.

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